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ABSTRACT

Many educators assert that the acquisition of thinking skills by students is of primary importance to science education today. This study was designed to examine the effect of an instructional approach on achievement in science process skills when compared to a more conventional method of science instruction. The DIAL(SPS)2, a directed approach to learning science process skills that incorporates several instructional and learning methodologies, was the focus of this study. It was used with two high school biology classes, and consisted of 12-14 laboratory activities specifically developed using this instructional model. The control group of two biology classes received the same basic instruction, but did not participate in the DIAL(SPS)2 experiments. The results of the study indicated that concrete operational thinkers benefitted from the DIAL(SPS)2 treatment while those with more advanced cognitive strategies benefitted from a more conventional instructional program. (TW)

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Development and Summative Evaluation of a Directed Inquiry Approach to Learning Science Process Skills in Biology

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Development and Evaluation of a Program for
Learning Science Process Skills in Biology

Introduction

One of the most important tasks faced by educators is to help students acquire thinking skills. Lawson (1985), in a recent review of research on formal reasoning and science teaching, points out that there is strong correlational evidence between deficiencies in rational thinking and poor achievement in science, math, history, and social studies. Reasoning ability of the student is an excellent predictor of achievement if that achievement is based upon the student's ability to generate and test hypotheses while investigating natural phenomena. Lawson asserts that the performance of formal Piagetian reasoning is scientific reasoning.

Despite the importance of thinking skills and scientific reasoning, recent studies concerning the status of science education in American schools have yielded evidence that inquiry is not being taught effectively (Barufaldi & Swift, 1980; Costenson & Lawson, 1986; Hurd, 1970; Hurd, Bybee, Kahle, and Yager, 1980; Nagalski, 1980; Welch, Klopfer, Aikenhead, and Robinson, 1981). Teachers complain that inquiry approaches are difficult to manage,

and are too difficult for the low and average ability students (Welch, et al., 1981). Costenson and Lawson (1986) reported reasons science teachers gave for not using inquiry. Among the reasons given were that students cannot read inquiry materials, outcomes of inquiry are too uncertain, most students are not capable of inquiry, regular biology classes have few formal thinkers, and students and teacher feel uncomfortable about inquiry.

The primary objective of this study was to examine the effect of the DIAL(SPS)2 approach on achievement in science process skills when compared to a more conventional method of science instruction. Specifically, three questions were addressed. First, what effect did the DIAL(SPS)2 treatment have on the acquisition of science process skills? Second, what effect did the DIAL(SPS)2 treatment have on the development of cognitive strategies? Third, how effective was the (DIAL(SPS)2) treatment for student who differed with respect to cognitive development. It was hypothesized that a directed approach would facilitate the learning of science process skills, would foster cognitive development, and would be more beneficial to students who were concrete operational reasoners.

Method

Treatment

DIAL(SPS)2 was a directed approach to learning science process skills that incorporated several instructional and learning methodologies that have been shown to be effective. Karplus (1979) has shown that the learning cycle (exploration, invention or concept introduction, and discovery or concept application) is an effective instructional strategy for helping students learn concepts and conceptual systems while concurrently fostering cognitive development. A focusing technique, based upon the learning cycle, was developed for delivery of the treatment (Germann, 1985b). During focusing, students attempt the skill on their own, appropriate and inappropriate responses are immediately discussed, the teacher models the skill, and the model is applied to the next skill. Gowin (1981) has developed the Vee diagram to facilitate problem solving by making more apparent the conceptual and methodological relationships of knowledge and their interconnections in problems solving. The Vee diagram was adapted to this treatment to reduce the complexity of problem solving. Advance Organizers (Ausubel, 1979) were used as part of DIAL(SPS)2 to take adavantage of information already present in the learner's previous knowledge in order to create a link with new knowledge needed to successfully address the problem in the lab activity. Concept maps (Novak, 1979)

help student reveal important relationships among ideas. These student-produced maps can be used as a diagnostic tool by the teacher to see if students understand concepts with the meaning intended. In addition, concept maps are a useful tool that students can use in the writing process. Writing is an additional strategy to help the student think, as inner knowledge and experience are related, knowledge is rearranged, material is "jogged" lose from memory, new connections are made, and thoughts that have not been though before are generated (Moffett, 1983).

Treatment Groups

Six units containing twenty lab exercises were written that integrated the above mentioned methodologies with the instruction, learning, and performance of the science process skills. During the seven month period from October through April, the two classes in the experimental group received 12 to 14 lab activities, depending on the number of interuptions and the time available. Each lab required several periods to conduct. The first lab of a unit typically took more time because two or three 45 minute periods were generally needed to develop student background knowledge to the point where they possessed the concepts required to understand and perform the activity. Following this preparation, prelab process skills required about two periods as each skill was highlighted and addressed step by

step. Another period was needed to perform the lab procedure and to collect the data. Postlab activities took one to two periods. When all classroom work was completed, students wrote a lab report that typically included the following parts: purpose, preface (advance organizer), introduction (background information), problem, hypothesis, variable to be tested, variable to be affected, variables to be held constant for a fair test, assumptions, prediction, procedure, data tables and graphs, conclusions, and discussion of results. The discussion included a restatement of the problem, hypothesis, and prediction; arguments concerning how the data proved the conclusion that was drawn; a listing of possible experimental error; a description of limitations and/or surprising results; a commentary of how knowledge gained in the lab can explain some phenomena in nature or in daily life; and suggestions for further experimentation.

The comparison group's treatment was much simpler. These students performed the same lab activities, but without the DIAL(SPS)2 approach. That is, background information was simply presented to the students in a paragraph or orally by the teacher. Students were given a purpose and an experimental procedure and then they performed the lab. These activities were generally completed within the double lab period. A lab report was then written that included purpose, procedures, data tables

and graphs, conclusions, and discussion of results. The discussion included a restatement of the problem hypothesis, and prediction; a discussion of how the data proved the conclusion that was drawn; and a discussion of possible experimental errors. The comparison group was able to complete all twenty of the lab activities.

Because of the difference in the treatments and in the time required to perform them, the experimental group spent about 80 hours of lab time while the comparison group had about 40 hours. The comparison group used the time difference on biology content. This included additional topics in heredity, infectious diseases, and plant anatomy.

Subjects

The sample consisted of four sections of general biology assigned to the investigator. Students were not assigned randomly but on the basis of academic ability. The less able students were chosen for the experimental group and the more able students were chosen for the comparison group in order to test the hypothesis in the most stringent way.

The experiment was conducted in the investigator's classroom for several reasons. While this represented a serious shortcoming of the study, logistical considerations made other approaches impractical. For example, biology teachers were widely scattered across the State of Maine.

The investigator lived and worked at the extreme northern boun- dary of the state, 200 miles from the nearest major city (population: 33,000) and over 400 miles from the southern border. The time, travel, and expense of finding teachers willing to participate in the study, training half of them to implement the DIAL(SPS)2 approach, monitoring the implementation and testing, and gathering the data were prohibitive.

In addition, there were several risks to a design in which the investigator evaluated his own treatment. The teacher's expectations and preconceived ideas may have affected his treatment of the two groups. Subtle differences in the treatment, testing, and scoring for the experimental and comparison groups may have introduced experimental bias into the study. In an effort to minimize these risks, the problem of experimental bias was stressed from the outset of the study. The hope was that by maintaining attention on the problem, it would be minimized.

Instruments

The research hypotheses was tested using a non-equivalent pretest-posttest design. Students were tested in August and September and again in May. Improvement in science process skills was measured by two instruments. The Test of Integrated Process Skills (TIPS) (Dillashaw & Okey, 1980) is a 36 item, 45 minute, paper and

pencil test for grades seven to twelve using non-specific content to assess the acquistion of five integrated process skills: state hypotheses, define operationally, identify variables, design investigations, and graphically analyze data. TIPS is a reliable instrument (M=18.99; SD=7.60; Cronbach's alpha=.89) that evaluated a number of skills addressed by this study.

The Processes of Biological Inquiry Test (PBIT) (Germann, 1985a) is a 35 item, 45 minute, paper and pencil test developed for this study. Items were selected from the BSCS Resource Book of Test Items (1974) that most closely corresponded to skills in the treatment: hypothesis, prediction, assumption, data and hypotheses, tables and graphs, supporting data, and evaluation. During field testing, PBIT yielded a mean score of 18.84, standard deviation of 6.97, and Cronbach's alpha reliability of .86. PBIT scores correlated .73 with the TIPS.

The Classroom Test of Formal Operations (TFO) (Lawson, 1978) was given to measure each student's level of cognitive development. Lawson reported a mean of 7.41, standard deviation of 4.27, and a KR-20 estimate of reliability of .78 for this 15 item test. Correlation between the TFO and Piagetian clinical interviews was .76.

SRA achievement scores, obtained from student records, were used as a measure of academic ability.

Statistical Analyses

To determine the effectiveness of the DIAL(SPS)2 program on the learning of science process skills, analysis of covariance was conducted, where science process skill measures served as the dependent variable and SRA achievement test served as the covariate. Similarly, the effect of the DIAL(SPS)2 program on cognitive development was also determined by analysis of covariance, using the cognitive development measure as the dependent variable and SRA achievement test as the covariate.

To determine if there were any interaction effects, ATI analyses were used. Measures of science process skills used as the dependent variable were TIPS, PBIT, and composite of both. Academic ability (SRA) and cognitive development (TFO) were the aptitude measures used. TFO posttest scores were used as the measure of cognitive development because the administration of this test was concurrent with that of the science process skills posttests. In addition, TFO posttest results correlated highly with the TFO pretest results.

Generalized regression equations for the experimental (E) and comparison (C) groups were

$$Y_j = A_E + B_E X_j + e_j \qquad \text{For } j = 1, \ldots, n \tag{1}$$

$$Y_j = A_C + B_C X_j + e_j \qquad \text{For } j = n+1, \ldots, N$$

where A represents the intercept constant and B represents the slope associated with the posttest (Y) on aptitude (X) regression.

To analyze ATI effects, the two within-group simple regressions were combined as

$$(2)\quad Y_j = a + b_1 T_j + b_2 X_j + b_3 T_j X_j + e$$

$$\text{for } j = 1, \ldots, N$$

where a, the intercept constant, was equivalent to A in equation 1; b_1 was the regression coefficient associated with treatment T; b_2, the regression coefficent associated with the covariate, was equal to Bc in equation 1; and b_3 was the regression coefficient associated with the interaction of T with the covariate X. b_3 was equivalent to the difference between the two within-group regression coefficients for the two groups, $b_3 = B_E - B_C$. For ATI analyses, unstandardized regression coefficients were used. If the within-group regression lines were parallel, b_3 would be 0; if the lines were non-parallel, b_3 would not be 0.

The within-group intercepts and slopes were obtained using the SPSSX scattergram procedure (SPSSX, 1983). These were used to plot the within-group regression lines for experimental and comparison groups as shown in Figures 1, 2, and 3. Interaction effects were determined with SPSSX regression procedure by examining the statistical significance of b_3 - the regression coffecient expressing

the degree to which the two within-group regression lines are non-parallel. Two composites were calculated by summing the standarized z scores for TIPS and PBIT. Treatment groups were recoded to 0 (comparison) and 1 (experimental). ATI terms were computed by taking the product of treatment groups and the covariate (TFO or SRA).

Results

As was expected, the comparison group had significantly higher means than the experimental group on TIPS, PBIT, and TFO pretests as well as SRA scores. The significant differences remained on the posttests (Table 1). Table 2 summarizes TFO results by Piagetian developmental level.

Table 1

A t test analysis of experimental and comparison group pretest and posttest means.

	Experimental			Comparison			Mean	
	N	Mean	SD	N	Mean	SD	Diff.	t-ratio*
Pretests								
TIPS	44	18.23	4.78	27	22.89	5.60	-4.66	-3.59
PBIT	44	18.70	4.64	27	23.30	6.16	-4.60	-3.34
TFO	44	5.80	2.36	27	9.22	3.09	-3.42	-4.79
SRA	44	512.05	58.47	27	590.58	74.49	-78.53	-4.59
Posttests								
TIPS	44	20.75	3.28	27	26.10	5.79	-5.44	-4.25
PBIT	44	21.55	5.21	27	25.40	5.78	-3.86	-3.02
TFO	44	7.25	3.28	27	10.00	3.26	-2,82	-3.54

* all t-ratios are significant (alpha = .05)

Table 2

IFD pretest and posttest measures of cognitive level for the experimental and comparison groups

Group		Piagetian Cognitive Level: Concrete Pre	Concrete Post	Concrete Change	Transitional Pre	Transitional Post	Transitional Change	Formal Pre	Formal Post	Formal Change
Exper.	N	19	14	-5	24	24	0	1	6	+5
	%	42%	32%	-10%	55%	55%	0%	2%	13%	+11%
Comp.	N	2	3	+1	18	13	-5	7	11	+4
	%	7%	11%	+3%	67%	48%	-19%	26%	41%	+15%

The first research hypothesis to this study was that the DIAL(SPS)2 treatment would have a significant effect on the posttest means of the experimental group as compared to the comparison group. To adjust the posttest means for existing differences between groups at the outset of the study, SRA achievement scores were employed as a covariate in the statistical analysis. While the difference between the experimental and comparison group means of TIPS was reduced, the comparison group means remained greater (Table 3). For PBIT, the mean for the experimental group became larger, but nonetheless was not significantly different from the comparison group (Table 3).

Table 3

Analysis of covariance of measures of science process skills and cognitive development by experimental and comparison groups with SRA achievement as covariate

Dependent Variable Posttest	Group Observed Means Exp.	Comp.	Group Adjusted Means Exp.	Comp.	F-ratio*
TIPS	20.77	26.42	22.71	23.20	.209
PBIT	21.49	25.77	23.37	22.66	.432
TFO	7.33	10.15	8.43	8.32	.016

* none of the F-ratios were significant.

TIPS and PBIT served to evaluate different objectives in the analytic mode. A lab practical (LAB) was used to evaluate the process skills in the practical mode (Tamir, 1972). Since multiple, correlated, dependent measures were used, multivariate analysis of variance was performed. Hotellings T-square, a multivariate t-test, was used to test simultaneously whether the two groups differed on several dependent variables (Norusis, 1985). As before, SRA achievement was used as a covariate. No significant difference was found ($df=6, 61$; $p>.05$). DIAL(SPS)2 treatment appears to have had no significant effect on the learning of science process skills.

The second research hypothesis was that the DIAL(SPS)2 treatment would have a significant effect on the posttest means of the experimental group as compared to the

comparison group. A t test analysis indicated that cognitive development in the comparison group was significantly (alpha<.05) greater than the experimental group when the study began. Analysis of covariance was done using the TFO as the dependent variable. Academic ability (SRA) was again used as the covariate. The difference between experimental and comparison group means was eliminated when this covariate was included (Table 3). A second analysis in which the TFO pretest served as the covariate produced essentially the same result with respect to means and significance. DIAL(SPS)2 appears to have had no significant effect on the development of cognitive strategies.

No significant ATI was found on any of the process skill measures when SRA served as the covariate. However, ATI were found when TFO scores were used as the covariate. Figure 1 shows this ATI for the TIPS posttest. The lines intersect at a TFO score of about 5 (df=3, 65; interaction beta= -.56; t= -2.34; p<.05).

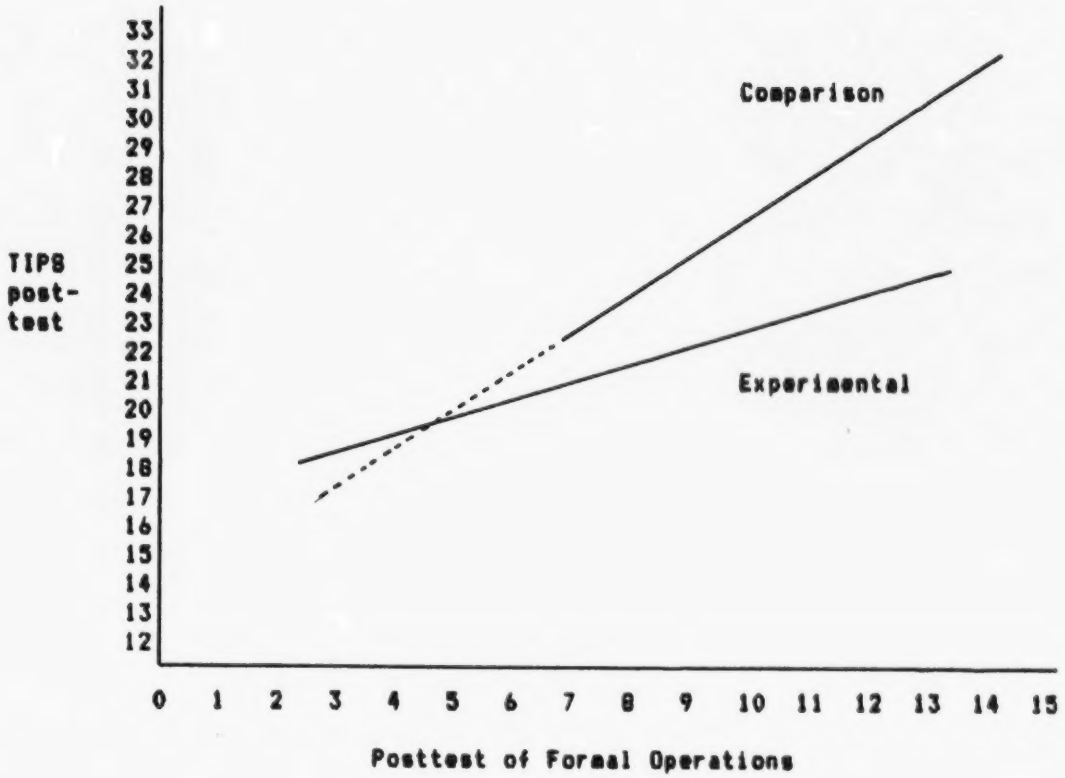

Figure 1: Aptitude-Treatment Interaction between treatment groups and cognitive development (TFO) on TIPS posttest.

ATI for the PBIT test as the dependent measure is shown in Figure 2. The lines intersect at a TFO score of about 6 (df=3, 65; interaction beta= -.55; t= -2.03; p<.05).

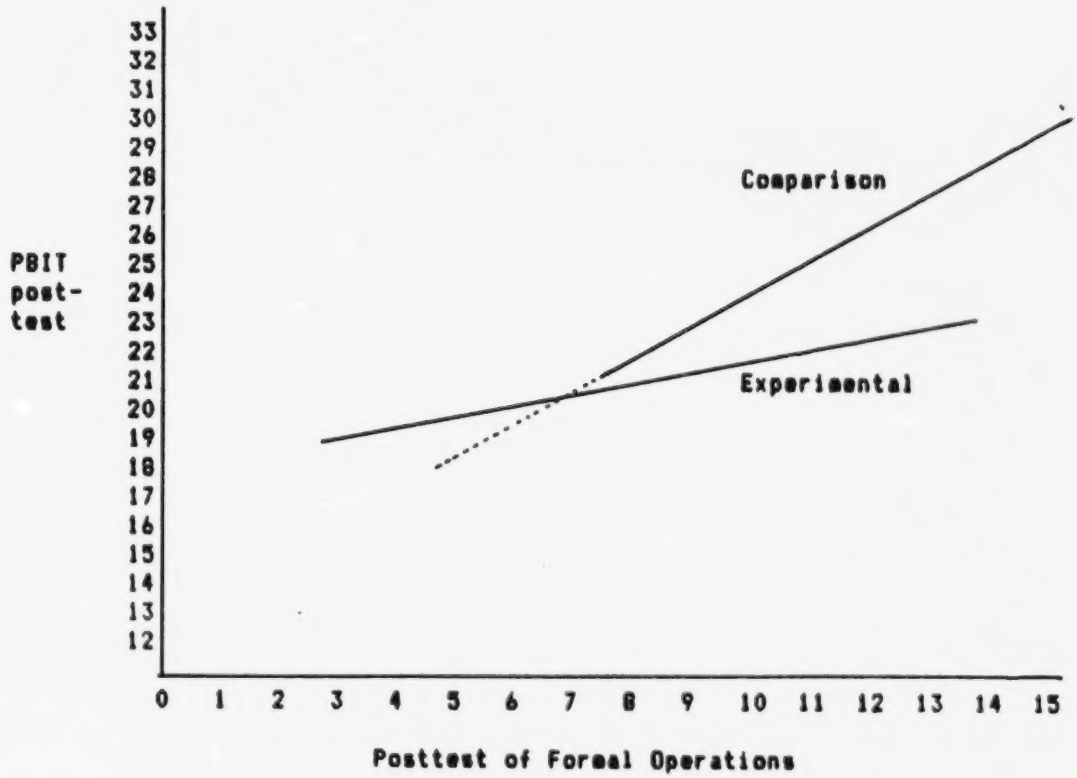

Figure 2: Aptitude-Treatment Interaction between treatment groups and cognitive development (TFO) on PBIT posttest.

On the TIPS and PBIT composite, the ATI between treatment groups and cognitive development is shown in Figure 3. These lines intersect at a TFO score of 6 (df=3, 65; interaction beta= -.60; t= -2.49; p<.05).

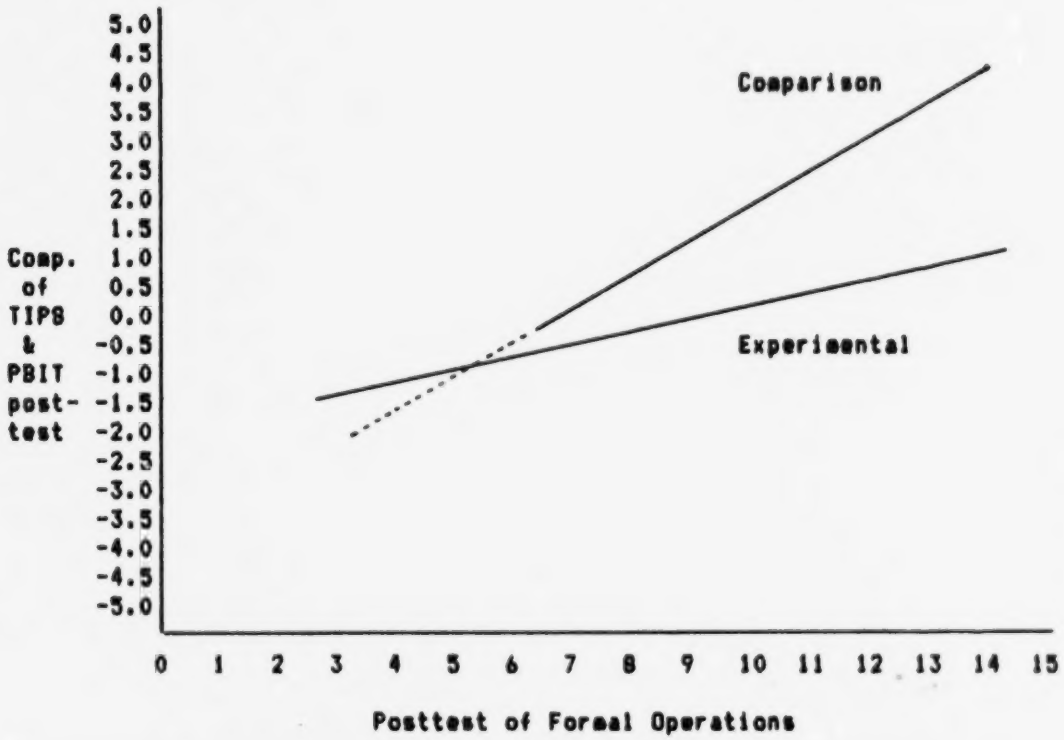

Figure 3: Aptitude-Treatment Interaction between treament groups and cognitive development (TFO) on composite of TIPS and PBIT.

Students with TFO scores less than 6 are classified as concrete operational reasoners. The interactions described above suggest that those students with lower cognitive development will perform better than student with higher cognitive dvelopment on TIPS and PBIT when they have been

exposed to DIAL(SPS)2 treatment. In contrast, transitional and formal operational thinkers may perform better when given a more traditional and less guided approach.

Discussion

In testing the hypothesis to the first question, multivariate t test employing TIPS and PBIT as the dependent variable yielded a non-significant t-ratio. DIAL(SPS)2 had no significant effect on the learning of science process skills. For the second question, an analysis of covariance in which the TFO posttest served as the dependent variable and SRA and TFO pretest served as the covariate similarly yielded no significant difference. DIAL(SPS)2 treatment appears to have no significant effect on cognitive development. Thus, the first and second research hypotheses were not confirmed.

The third research hypothesis was supported by aptitude-treatment interaction analysis (ATI). ATI analyses revealed a significant interaction of cognitive development with treatment group on the learning of science process skills. These data suggest that concrete operational thinkers benefited from the DIAL(SPS)2 treatment while those with more advanced cognitive strategies benefited from a more conventional instructional program. No such interaction was found between groups and SRA achievement scores on process skills.

According to Piaget, cognitive development depends upon disequilibrium. Students need to find themselves in situations where less sophisticated strategies are inadequate before development can take place, and then only if the student does not maintain his or her equilibrium by ignoring the problem and not attending to possible solutions. The latter is too often the case for student who have met with a lack of success so often that they now avoid failure with indifference. It was hoped that a second benefit of the DIAL(SPS)2 approach would have been to provide situations in which disequilibrium would occur and thereby facilitate cognitive development.

That an interaction may exist is consistent with Piagetian learning theory. It seems reasonable that students without at least some formal operational strategies would learn more effectively when problem solving was attacked step by step, highlighting each skill as it was addressed. Students with formal cognitive strategies would have been hindered to some degree by the slow pace of the DIAL(SPS)2 approach. Since so much of the problem solving process has been made explicity for them, they may not have been challenged to the point of disequilibrium that would have fostered the further development of their own problem solving skills and strategies. The approach may actually have been a handicap. If these hypotheses are borne out in further investigations, the implications are that care needs

to be taken to match instruction to the learning abilities and skills of each student. In this case, more guidance for concrete reasoners and less guidance for more advanced reasoners may be appropriate.

If inquiry instruction is avoided in our science classrooms because teachers feel that students are not capable of inquiry, perhaps a more directed approach would provide better results. Concrete operational thinkers may learn to use science process skills if they are provided more direction that focuses on relevant background, attend to each skill in a step by step manner, and apply the background and previous process skills to the performance of subsequent skills.

These ATI results need to be viewed cautiously since the number of subjects in this study was low for ATI studies and since the groups were significantly different from each other with respect to academic ability and cognitive development at the outset of the study. Scores in the experimental group covered a lower range than in the comparison group. There were only three students in the comparison group that were at or below the point of intersection on the ATI analysis. There were few concrete operational and low transitional students receiving the comparison treatment. Results are based upon extrapolation past the point of intersection. There is no direct data on how student who were concrete operational mught have

performed on the science process skills measures after receiving comparison group treatment. Conversely, there were many fewer students who were formal operational reasoners in the experimental group than in the comparison group. Unfortunately, the fact that the experimental and comparison group were so different in ability and cognitive development prevents us from drawing unequivocal conclusions concerning how less able students might have fared with or without treatment.

Further research is required to verify and clarify the conclusions drawn here. In preparation for such a study, easy to use teacher materials for the DIAL(SPS)2 curriculum should be developed. The study itself should involve the classes of several teachers, some randomly assigned to using the DIAL(SPS)2 curriculum while others present their labs in their usual manner.

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